

## POLYMERISATION CATALYSTS

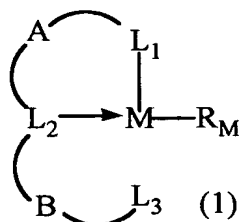
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The present invention relates to new compounds having an element of group 12 and having a tridentate ligand, a process for their preparation and their use in particular as polymerization catalysts.

5 The use of derivatives having an element of group 12 but having porphyrin type ligands (Inoue, Acc. Chem. Res., (1996) 29, 39) as catalysts for the polymerization of heterocycles is already known.

10 However, it has been shown that each type of catalyst used for the polymerizations or copolymerizations, produces different polymers or copolymers respectively (Jedlinski et al., Macromolecules, (1990) 191, 2287; Munson et al., Macromolecules, (1996) 29, 8844; Montaudou et al., Macromolecules, (1996) 29, 6461). The problem is therefore to find new catalytic systems in order to obtain new polymers or copolymers, and more particularly block copolymers. The use of catalytic systems allows control of the chain formation of monomers leading to specific copolymers having the appropriate properties. This is particularly useful for biocompatible copolymers, the biodegradation of which is  
15 influenced by this chain formation.

Therefore a subject of the invention is the products of general formula 1



in which

20 M represents an element of group 12;  
 $R_M$  represents the hydrogen atom, a halogen atom, or an alkyl, cycloalkyl, aryl, alkoxy, cycloalkoxy, aryloxy, alkylthio, cycloalkylthio, arylthio, amino, alkylamino, dialkylamino, cycloalkylamino, di(cycloalkyl)amino, alkyl(cycloalkyl)amino, arylamino, diarylamino, alkylaryl amino or  
 25 (cycloalkyl)aryl amino radical;

- A and B represent, independently, a carbon chain of 2 to 4 carbon atoms, optionally substituted by one or more of the following substituted (by one or more identical or different substituents) or non-substituted alkyl, cycloalkyl or aryl radicals, in which said substituent is a halogen atom, the alkyl, nitro or cyano radical;
- 5  $L_1$  and  $L_2$  represent, independently, a group of formula  $-E_{15}(R_{15})$  - in which  $E_{15}$  is an element of group 15 and  $R_{15}$  represents the hydrogen atom; one of the following substituted (by one or more identical or different substituents) or non-substituted alkyl, cycloalkyl or aryl radicals, in which said substituent is a halogen atom, the alkyl, nitro or cyano radical; a radical of formula  $-E_{14}RR'R''$  in which  $E_{14}$  is an element of group 14 and R, R' and R'' represent, independently, the hydrogen atom or one of the following substituted (by one or more identical or different substituents) or non-substituted alkyl, cycloalkyl, aryl, alkoxy, cycloalkoxy, aryloxy, alkylthio, cycloalkylthio or arylthio radicals, in which said substituent is a halogen atom, the alkyl, nitro or cyano radical; or a radical of formula  $-SO_2Q$  in which Q represents a halogen atom, an alkyl, haloalkyl or aryl radical optionally substituted by one or more substituents chosen from the alkyl, haloalkyl and halogen radicals.
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- 20  $L_3$  indifferently represents a group of formula  $-E'_{15}(R'_{15})(R''_{15})$  or  $-E_{16}(R_{16})$  in which  $E'_{15}$  is an element of group 15 and  $E_{16}$  is an element of group 16 and  $R'_{15}$ ,  $R''_{15}$  and  $R_{16}$  represent, independently, the hydrogen atom; one of the following substituted (by one or more identical or different substituents) or non-substituted alkyl, cycloalkyl or aryl radicals, in which said substituent is a halogen atom, the alkyl, nitro or cyano radical; a radical of formula  $-E'_{14}TT'T''$  in which  $E'_{14}$  is an element of group 14 and T, T' and T'' represent, independently, the hydrogen atom or one of the following substituted (by one or more identical or different substituents) or non-substituted alkyl, cycloalkyl, aryl, alkoxy, cycloalkoxy, aryloxy, alkylthio, cycloalkylthio or arylthio radicals, in which said substituent is a halogen atom, the alkyl, nitro or cyano radical; or a radical of formula  $-SO_2Q'$  in which Q' represents a halogen atom, an alkyl, haloalkyl or aryl radical optionally substituted by one or more substituents chosen from the alkyl, haloalkyl and halogen radicals.
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In the definitions indicated above, the expression halogen represents a fluorine, chlorine, bromine or iodine atom, preferably chlorine. The expression alkyl preferably represents a

linear or branched alkyl radical having 1 to 6 carbon atoms and in particular an alkyl radical having 1 to 4 carbon atoms such as the methyl, ethyl, propyl, isopropyl, butyl, isobutyl, sec-butyl and tert-butyl radicals.

5 The term haloalkyl preferably designates radicals in which the alkyl radical is as defined above and is substituted by one or more halogen atoms as defined above such as, for example, bromoethyl, trifluoromethyl, trifluoroethyl or also pentafluoroethyl. The alkoxy radicals can correspond to radicals in which the alkyl radical is as defined above. The methoxy, ethoxy, isopropoxy or tert-butoxy radicals are preferred. The alkylthio radicals preferably represent radicals in which the alkyl radical is as defined above such as, 10 for example, methylthio or ethylthio. The alkylamino and dialkylamino radicals preferably represent the radicals in which the alkyl radical is as defined above such as, for example, methylamino or dimethylamino.

The cycloalkyl radicals are chosen from saturated or unsaturated monocyclic cycloalkyls. The saturated monocyclic cycloalkyl radicals can be chosen from the radicals having 3 to 7 15 carbon atoms such as cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl or cycloheptyl radicals. The unsaturated cycloalkyl radicals can be chosen from cyclobutene, cyclopentene, cyclohexene, cyclopentadiene and cyclohexadiene radicals. The cycloalkoxy radicals can correspond to radicals in which the cycloalkyl radical is as defined above. The cyclopropyloxy, cyclopentyloxy or cyclohexyloxy radicals are preferred. The 20 cycloalkylthio radicals can correspond to radicals in which the cycloalkyl radical is as defined above such as for example cyclohexylthio. The cycloalkylamino and di(cycloalkyl)amino radicals can correspond to radicals in which the cycloalkyl radical is as defined above such as for example cyclohexylamino and di(cyclohexyl)amino.

The aryl radicals can be of mono or polycyclic type. The monocyclic aryl radicals can be 25 chosen from the phenyl radicals optionally substituted by one or more alkyl radicals, such as tolyl, xylyl, mesityl and cumenyl. The polycyclic aryl radicals can be chosen from the naphthyl, anthryl and phenanthryl radicals. The aryloxy radicals can correspond to radicals in which the aryl radical is as defined above. The phenoxy, 2,4,6-tritertibutylphenoxy, tolyloxy or mesityloxy radicals are preferred. The arylthio radicals preferably designate the 30 radicals in which the aryl radical is as defined above such as for example in phenylthio radicals. The arylamino and diarylamino radicals preferably designate radicals in which the aryl radical is as defined above such as, for example, phenylamino or diphenylamino radicals.

35 The alkyl (cycloalkyl)amino radicals can correspond to radicals in which the alkyl and cycloalkyl radicals are as defined above such as, for example methyl(cyclohexyl)amino. The alkyl arylamino radicals preferably designate radicals in which the alkyl and aryl

radicals are as defined above such as, for example methylphenylamino. The (cycloalkyl)aryl amino radicals can correspond to the radicals in which the cycloalkyl and aryl radicals are as defined above such as, for example (cyclohexyl)phenylamino.

The compounds of formula 1 can be presented in the form of a monomer or of a dimer and more particularly the compounds of formula 1 in which M represents a zinc atom generally presented in dimer form.

A more particular subject of the invention is the products of general formula 1 as defined above, characterized in that

$R_M$  represents an alkyl radical;

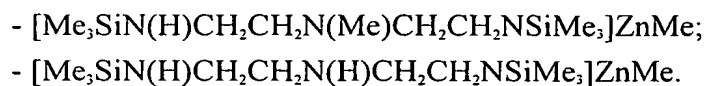
A and B represent, independently, a carbon chain with 2 to 4 carbon atoms;

$L_1$  and  $L_2$  represent, independently, a radical of formula  $-E_{15}(R_{15})-$  in which  $E_{15}$  is a nitrogen or phosphorus atom and  $R_{15}$  represents a hydrogen atom or a radical of formula  $-E_{14}RR'R''$  in which  $E_{14}$  represents a carbon or silicon atom and R, R' and R'' represent, independently, the hydrogen atom or an alkyl radical;

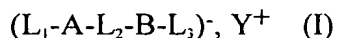
$L_3$  represents a radical of formula  $-E'_{15}(R'_{15})(R''_{15})$  in which  $E'_{15}$  is a nitrogen or phosphorus atom, and  $R'_{15}$  and  $R''_{15}$  represent, independently, a hydrogen atom or a radical of formula  $-E'_{14}TT'T''$  in which  $E'_{14}$  represents a carbon or silicon atom and T, T' and T'' represent, independently, the hydrogen atom or an alkyl radical.

Preferably, M represents a zinc atom. Preferably also,  $R_M$  represents a methyl radical; A and B represent, independently, a carbon chain with 2 carbon atoms;  $L_1$  and  $L_2$  represent, independently, a radical of formula  $-E_{15}(R_{15})-$  in which  $E_{15}$  is a nitrogen atom and  $R_{15}$  represents a hydrogen atom, a methyl, ethyl, propyl, isopropyl radical or a radical of formula  $-E_{14}RR'R''$  in which  $E_{14}$  represents a silicon atom and R, R' and R'' represent, independently, the hydrogen atom or a methyl, ethyl, propyl or isopropyl radical;  $L_3$  represents a radical of formula  $-E'_{15}(R'_{15})(R''_{15})$  in which  $E'_{15}$  is a nitrogen atom, and  $R'_{15}$  and  $R''_{15}$  represent, independently, a hydrogen atom, a methyl, ethyl, propyl, isopropyl radical or a radical of formula  $-E'_{14}TT'T''$  in which  $E'_{14}$  represents a silicon atom and T, T' and T'' represent, independently, the hydrogen atom or a methyl, ethyl, propyl or isopropyl radical.

More particularly, a subject of the invention is the products described hereafter in the examples, in particular the products corresponding to the following formulae:



A subject of the invention is also a process for the preparation of the products of general formula 1 as defined above, characterized in that a product of formula I



in which  $L_1$ , A,  $L_2$ , B and  $L_3$  have the meanings indicated above and Y represents the hydrogen atom, a metal or a metallic group, is reacted with a product of formula II



in which M and  $R_M$  have the meanings indicated above and Z represents a parting group, in order to obtain a product of formula I as defined above.

The reaction of a compound of general formula I with a compound of general formula II in order to obtain a compound of general formula I, can be carried out under an inert  
10 atmosphere such as under a freon or argon atmosphere, in an aprotic solvent, at a temperature comprised between -90 and +50° C. The compounds I thus obtained are purified by standard purification methods.

As aprotic solvent, aromatic hydrocarbons such as benzene, toluene; aliphatic hydrocarbons such as pentane, heptane, hexane, cyclohexane; ethers such as diethylether,  
15 dioxane, tetrahydrofuran, ethyltertiobutyl ether can be used.

In the Compounds I, Y represents the hydrogen atom, a metal or a metallic group. The metallic group can be a compound of formula  $R'''M_1$  or  $R'''_3M_2$  in which  $R'''$  represents a halogen atom, or indifferently, an alkyl, cycloalkyl, aryl, alkoxy, cycloalkoxy or aryloxy radical as previously defined,  $M_1$  is a zinc or mercury atom or an alkaline-earth such as  
20 magnesium and  $M_2$  a tin or lead atom; preferably, the metallic group is chosen from the MgBr, ZnMe, SnMe<sub>3</sub>, SnBu<sub>3</sub> or PbMe<sub>3</sub> groups. The metal can be an alkali metal chosen from lithium, sodium or potassium.

In the compounds II, Z represents a parting group such as a halogen atom, an alkyl, cycloalkyl, alkoxy, aryl, aryloxy, amino, alkylamino or dialkylamino group as previously  
25 defined, or also a methanesulphonyloxy, a benzenesulphonyloxy, p-toluenesulphonyloxy group.

The starting products of formula I are known products or can be prepared from known products. For their synthesis, the following references can be mentioned: Cloke et al., J. Chem. Soc., Dalton Trans. (1995) 25; Wilkinson and Stone, Comprehensive  
30 Organometallic Chemistry (1982) vol. 1, 557.

The products of formula II are commercially available or can be manufactured by methods known to a person skilled in the art.

A subject of the invention is also the use of the products of formula 1 as defined above, as catalysts for carrying out (co)polymerization, that is to say of polymerization or copolymerization. Whilst carrying out (co)polymerization, the compounds according to the invention also play the role of chain initiator and/or of regulator.

- 5 The compounds of formula 1 are particularly useful for carrying out the polymerization of heterocycles. The heterocycles can contain one or more heteroatoms of groups 15 and/or 16, and have a size ranging from three to eight members. As an example of heterocycles corresponding to the previous formulation, epoxides, thioepoxides, cyclic esters or thioesters such as lactones, lactames and anhydrides can be mentioned.
- 10 The compounds of formula 1 are also particularly useful for carrying out the (co)polymerization of cyclic esters. As an example of cyclic esters, the polymer cyclic esters of lactic and/or glycolic acid can be mentioned. Random or block copolymers can be obtained depending on whether the monomers are introduced together at the start of the reaction, or sequentially during the course of the reaction.
- 15 A subject of the invention is also a process for the preparation of random or block copolymers, or polymers which consists of bringing into contact one or more monomers, a chain initiator and/or a regulator, a polymerization catalyst and optionally a polymerization solvent, said process characterized in that the chain initiator and/or chain regulator and the polymerization catalyst are represented by the same compound which is chosen from the
- 20 compounds of formula (1) as defined above.

The (co)polymerization can be carried out either in solution or in supercooling. When the (co)polymerization is carried out in solution, the reaction solvent can be the (or one of the) substrate(s) used in the catalytic reaction. Solvents which do not interfere with the catalytic reaction itself, are also suitable. As an example of such solvents, saturated or

25 aromatic hydrocarbons, ethers, aliphatic or aromatic halides can be mentioned.

The reactions are carried out at temperatures comprised between ambient temperature and approximately 250° C; the temperature range comprised between 40 and 200° C is most advantageous. The durations of the reactions are comprised between a few minutes and 300 hours, and preferably between 5 minutes and 72 hours.

- 30 This (co)polymerization process is particularly suitable for obtaining (co)polymers of cyclic esters, in particular the polymer cyclic esters of lactic and/or glycolic acid. The products obtained such as the biodegradable glycolic lactic copolymers, are advantageously used as a support in sustained release therapeutic compositions. The process is also particularly well suited to the polymerization of epoxides, in particular propylene oxide.

The polymers obtained are compounds which can be used for the synthesis of organic liquid crystals or also as semi-permeable membranes.

The invention also relates to the polymers or copolymers which can be obtained by carrying out a process as described above.

- 5 The following examples are presented to illustrate the above procedures and should in no way be considered as limiting the scope of the invention.

**Example 1:**  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{N}(\text{H})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$  (in dimer form)

4.3 g (17.7 mmol) of  $[(\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2)_2\text{NH}]$  and 30 ml of toluene are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon.

- 10 The reaction mixture is cooled down to -78 C, then 8.8 ml (17.7 mmol) of a 2M solution of  $\text{ZnMe}_2$  in toluene is introduced. The reaction mixture is brought to ambient temperature then left under agitation for 18 hours at ambient temperature. After evaporating the solvent, an orange oil is obtained. The desired compound is isolated in the form of colourless crystals by crystallization at -20 C from pentane (5 ml) (yield 50 %). This  
15 compound is characterized by multinuclear magnetic resonance spectroscopy and X-ray diffraction (Figure 1 and Table 1 below).

**Example 2:**  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{N}(\text{Me})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$  (in dimer form)

1.1 g (4.2 mmol) of  $[(\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2)_2\text{NMe}]$  and 20 ml of toluene are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon.

- 20 The reaction mixture is cooled down to -78 C, then 2.1 ml (4.2 mmol) of a 2M solution of  $\text{ZnMe}_2$  in toluene is introduced. The reaction mixture is brought to ambient temperature then left under agitation for 3 hours at ambient temperature. After evaporating the solvent, an orange oil is obtained. The desired compound is isolated in the form of white crystals by crystallization at -20° C from pentane (5 ml) (yield 50 %). This compound is  
25 characterized by multinuclear magnetic resonance spectroscopy.

**Example 3:** preparation of a poly(D,L-lactide)

0.045 g (0.14 mmol) of  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{-N}(\text{H})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$  and 100 ml of toluene are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon. The reaction mixture is brought to 80°C. 6.24 g (43.2 mmol) of  
30 D,L-lactide is then added. The reaction mixture is left under agitation at 80 °C for 42 hours. The polymer is characterized by carbon and proton NMR; the conversion of the monomer is 96 %. According to a GPC analysis (Gel Permea Chromatography) using a calibration carried out from polystyrene (PS) standards polystyrene standards of masses

761 to 400000, the sample is comprised of polymers having high masses ( $M_w = 40400$  Dalton).

**Example 4:** preparation of a block (D,L-lactide / glycolide) copolymer

0.15 g (0.43 mmol) of  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{-N}(\text{Me})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$ , 3.50 g (24 mmol) of D,L-lactide and 80 ml of toluene are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon. The reaction mixture is left under agitation at 85 °C for 18 hours. Proton NMR Analysis of the allows verification that the conversion of the monomer is greater than 94 %. 2.25 g (19.4 mmol) of glycolide is added over a period of 11 days to the previous solution maintained under agitation at 80° C. Analysis of an aliquot by proton NMR shows that a copolymer is formed. The ratio of the signal integrals corresponding to the polylactide part (5.20 ppm) and polyglycolide part (4.85 ppm) is 4/1. According to a GPC analysis, using a calibration carried out from PS standards of masses of 761 to 400000, this copolymer is a mixture of macromolecules having similar masses ( $M_w/M_n = 1.63$ ;  $M_w = 2960$  Dalton).

**Example 5:** preparation of a random (D,L-lactide / glycolide) copolymer

0.05 g (0.15 mmol) of  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{-N}(\text{Me})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$ , 6.66 g (45 mmol) of D,L-lactide and 1.53 g (13 mmol) of glycolide are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon. The reaction mixture is heated to 180° C for 2 hours. The polymer is characterized by proton NMR; the conversion of monomers is total. The ratio of the signal integrals corresponding to the polylactide part (5.20 ppm) and the polyglycolide part (4.85 ppm) is 4/1. According to a GPC analysis, using a calibration carried out from PS standards of masses of 761 to 400000, the sample comprises polymers with a polydispersity ( $M_w/M_n$ ) of 2.27 and molecular weight ( $M_w$ ) of 16271 Dalton.

**Example 6:** preparation of a random (D,L-lactide / glycolide) copolymer having a lactide/ glycolide composition close to 70/30

0.024 g (0.073 mmol) of  $[\text{Me}_3\text{SiN}(\text{H})\text{CH}_2\text{CH}_2\text{-N}(\text{H})\text{CH}_2\text{CH}_2\text{NSiMe}_3]\text{ZnMe}$ , 1.98 g (13.6 mmol) of D,L-lactide and 0.68 g (5.8 mmol) of glycolide are successively introduced into a Schlenk tube equipped with a magnetic stirrer and purged under argon. The reaction mixture is left under agitation at 180° C for 2 hours. Analysis by proton NMR allows verification that the conversion of the monomers is 98 % lactide and 100% glycolide. The ratio of the signal integrals corresponding to the polylactide part (5.20 ppm) and the polyglycolide part (4.85 ppm) the composition of the copolymer to be evaluated at 65% of lactide and 35% of glycolide. According to a GPC analysis, using a calibration carried out



from PS standards of masses 761 to 400000, this copolymer is a mixture of macromolecules ( $M_w/M_n = 2.84$ ) of high masses ( $M_w = 34500$  Dalton).

**Table 1:** Lengths of the selected bonds (in Angström) and bond angles (in degrees) for the compound of Example 1

Zn(1)-C(1)	1.989(2) Å	C(5)-C(6)	1.519 (3) Å
Zn(1)-N(1)	2.086(2) Å	C(6)-N(2)	1.475 (3) Å
Zn(1)-N(2)	2.145 (2) Å	N(2)-C(7)	1.472 (3) Å
Zn(1)-N(1A)	2.084 (2) Å	N(2)-C(7)	1.472 (3) Å
N(1)-If(1)	1.725 (2) Å	C(7)-C(8)	1.519 (3) Å
N(3)-If(2)	1.711 (2) Å	C(8)-N(3)	1.453 (3) Å
N(1)-C(5)	1.483 (3) Å		
N(1)-Zn(1)-N(2)	85.1(1) °	Si(1)-N(1)-Zn(1)	119.5 (1) (2) °
N(1)-Zn(1)-C(1)	129.2 (1) °	Si(1)-N(1)-Zn(1A)	120.8 (1) °
N(1)-Zn(1)-N(1A)	93.7 (1) °	Si(1)-N(1)-C(5)	112.7 (1) °
N(2)-Zn(1)-C(1)	112.1 (1) °	Zn(1)-N(1)- Zn(1A)	86.3 (1) °
N(2)-Zn(1)-N(1A)	109.4 (4) °	Zn(1)-N(1)-C(5)	106.2 (1) °
C(1)-Zn(1)-N(1A)	120.1 (1) °	Zn(1A)-N(1)-C(5)	108.0 (1) °